On the influence of diffraction on image formation in the presence of aberrations

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SUMMARY.

The present thesis deals with investigations on the third order aberrations of optical systems (astigmatism, coma and spherical aberration). The diffraction patterns are photographed for small amounts of aberration and compared with theory. Moreover, they are photographed for larger amounts of aberration. It appears that even then the figures show considerable deviations from those expected according to geometrical optics. These deviations are explained in detail by applying the general theory of diffraction to this case. Finally the method of the coherent background, which is used for the examination of astigmatism, is discussed.

In Chapter I a short survey is given of the theory of aberration as has been developed by B. R. A. Nijboer in his thesis. The theory is extended in some respects; the intensity in the aberration figure is discussed as it would follow from geometrical theory and the diffraction patterns are calculated for larger amounts of aberration than were dealt with before. In all three cases the general term of the expansion of the diffraction integral is determined, which in the cases of astigmatism and spherical aberration simplifies the calculation for larger amounts of aberration considerably. We have calculated the diffraction pattern for $\beta_{22} = 4$ in the case of astigmatism (fig. 4) and for $\beta_{31} = 9$ ($\beta'_{31} = 3$) in the case of coma (fig. 6). (For the definitions of β_{nm} and β'_{nm} we refer to p. 10 and p. 11). It appears that the deviations from the geometrical figures are still very large. Furthermore the "definition" in the presence of astigmatism is discussed with respect to the intensity at the centre of the figure as would follow from geometrical theory (fig. 5). From this also it may be seen that the aberration figure does not change into the geometrical one with increasing β.

In Chapter II the aberration figure in presence of pure astigmatism is examined experimentally in the plane midway between the two focal lines. Astigmatism is obtained with a symmetrical biconvex lens with an enlargement one, thus excluding coma. The amount of astigmatism is varied either

by varying the inclination of the lens, or by varying the diameter of the diaphragm aperture. The diaphragm remains always perpendicular to the beam. The lightsource is a pinhole, the diameter of which is so small that the light is coherent over the whole aperture.

First the diffraction pattern is examined for those amounts of astigmatism for which they are calculated theoretically, namely for $\beta_{22} = 1$ and $\beta_{22} = 4$. Moreover exposures are made with coherent background. These diffraction pattern are compared with the theoretical ones. A very good agreement is found, also as to the phase. Then the cases with a larger amount of astigmatism are examined. It appears that the aberration figures do not become circular; on the contrary, the figures show a cushion-like shape with four tips and with a very complicated internal structure. (Plate I, 5—8). Applying the general theory of diffraction, it is shown that the aberration figure arises from superposition of the geometric optical wave and a diffraction wave emerging from the boundary. This explanation is tested by various experiments on the diffraction at the edge of the diaphragm aperture and the results are in excellent agreement. For instance, the figures of Plate I—11 and Plate I—12 show a remarkable resemblance. (Plate I—11 has been obtained by replacing the diaphragm aperture by an annular slit of the same diameter and Plate I—12 shows the aberration figure in the plane of one of the focal lines). The transition of the aberration figure with small to that with large β_{22} may easily be understood now.

In Chapter III we investigate the aberration figure if coma only is present. Pure coma is obtained from an ordinary achromatic telescope objective by shifting its components laterally in opposite direction. The amount of coma is proportional to the shift and to the third power of the aperture. As for large β_{31} the shape of the aberration figure passes into the geometrical one, the amount of coma can be determined from the diameter of the geometrical figure.

Also in this case we find that for small β_{31} the aberration figure in the focal plane (fig. 20 and 21) is in agreement with that following from the diffraction theory and for large β_{31} the figure again shows considerable deviations from the geometrical one; the shape of the figure is similar to that expected geometrically, but, contrary to the geometrical figure the pattern has a very beautiful structure (Plate II—3). From geometrical theory it follows that through each point of the receiving plane two or four rays pass. These rays being coherent will interfere and give rise to the observed structure. The influence of the diffraction appears to be much smaller. Finally the development of the aberration figure with increasing β_{31} is discussed.

In the same manner as with astigmatism and coma, spherical aberration is experimented on in Chapter IV. It is obtained from the positive lens of a telescope objective; the amount of it is varied by varying the diameter of the diaphragm aperture. Also in this case the agreement of the experimental results with the theoretical ones for small β_{40} is very good (fig. 20). For large β_{40} we have examined the aberration figure in different planes, for instance, in the paraxial focal plane, in the plane midway between paraxial and marginal focus and in the plane through "the circle of least confusion". The aberration figures appear to consist of concentric rings arising either from interference (Plate III—3) or from diffraction at the edge of the diaphragm aperture (Plate IV—2). Again the development of the aberration figure with increasing β_{40} is discussed.

In Chapter V the method of the coherent background is explained. Moreover some problems relating to the degree of coherence are discussed. The method of the coherent background, developed by Prof. F. Zernike some years ago, is illustrated by the diffraction of a slit, where the advantages of this method are easily to be seen. The image plane is illuminated faintly with coherent light, which interferes with the diffraction image. Two methods producing the coherent background are discussed and it is calculated which of them, under certain circumstances, is the more favourable. The phase of the coherent background may be varied by evaporating on the glass-plate transparent layers of different metals. A method is described to determine this phase change. Notwithstanding the simplicity of this method, the phaseshift can be determined very accurately.

Finally the method of the coherent background is illustrated with some photographs of diffraction images, respectively of a slit, a straight edge and a circular aperture (Plate IV).
